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The use of GIS and Remote Sensing in the study of Minoan Town Planning at Gournia

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Abstract. Harriet Ann Boyd (Hawes) excavated the Minoan town of Gournia between 1901-1904 and produced a prompt and thorough publication in 1908, that included a large multi-colored drawing of the excavated town, one that has been frequently reproduced until the present. A modern reassessment of the organization of the town has been underway for a number of years by a research team of the University of Pennsylvania Museum. Utilizing the modern techniques of electronic total station survey, GIS and remote sensing, and employing the use of a low level balloon photograph, a new digital plan and database of the Minoan town is being created. The new database will include orientation and area data for road, house, block, palace and shrine. A 1 m. resolution satellite image has been utilized for studies of the landscape in the region of the Minoan town.

Keywords. GIS, remote sensing, electronic total station survey, Minoan, town planning.

1 Introduction

During the years 1901-1904 Harriet Ann Boyd (Hawes) excavated the Minoan town of Gournia, located on the north coast of north-central Crete near the Isthmus of Hierapetra and south of the Gulf of Mirabello. The work was carried out under the auspices of the American Exploration Society of Philadephia, an organization with an affiliation to the University of Pennsylvania. Although the original name of the Minoan town is not known, the site remains to this day one of the most extensively excavated Minoan towns on Crete. The town is largely of Late Minoan date, ca. 1500 B.C., with some earlier Middle Minoan and some later Late Minoan evidence.

2 Gournia Town Plan

2.1 Hawes plan 1908

Hawes published in 1908 an excavation volume that was advanced for its day, *Gournia, Vasilike and Other Prehistoric Sites on the Isthmus of Hierapetra*, Philadelphia. Included in the publication was a multi-colored ground plan of the excavated site (Fig. 1). The map was the work of Herr Sejk although Harriet Boyd Hawes was responsible for the labeling of the plan including the discrimination of floor levels, above and below threshold level. The plan identifies three chronological sequences of occupation in the town: red for Middle Minoan, white for Town Period (Late Minoan I) and blue for the Reoccupation period, Late Minoan III. Further discrimination in the town plan is made for different masonry types: ashlar, rubble and cement. Partition walls above and below the main entrance are also identified. Two sections through the town are included at the top of the original drawing.

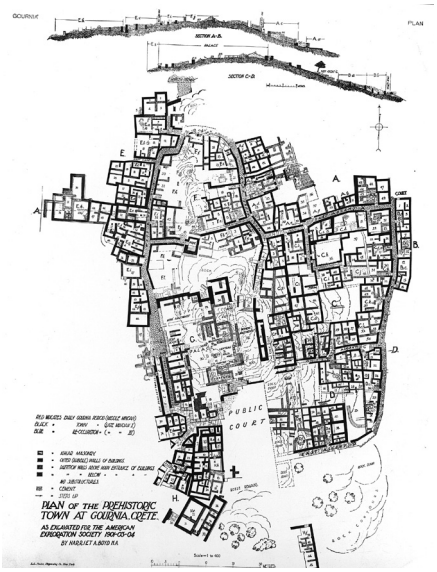

Fig. 1. *Harriet Boyd Hawes plan of Gournia, (reproduced in black and white) 1908.*

2.2 Digitized plan, 1985-1987

Under the supervision of the senior author, an undergraduate at the University of Pennsylvania, Douglas Arbittier, undertook a preliminary study of the organization of the town plan of Gournia. Arbittier digitized the original Hawes plan of 1908 and began a study of the planning of the Minoan town. In his digitized drawing he adhered to the format, organization and conventions of the original plan of the town and also included the same chronological identifications (**Fig. 2**).

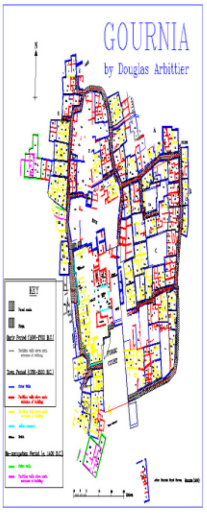

Fig. 2. *Digitized plan of Hawes by Douglas Arbittier.*

2.3 Methodological and Interpretative Challenges

During the subsequent re-assessment of the town plan by Romano and Arbittier, during the years 1987-1989, several methodological and interpretative problems were identified. At that time we were using AutoCAD 2.17 which was an early version of AutoCAD with limited capabilities by today's standards. The digitizing was done utilizing a small digitizing tablet, 15" X 15," which meant that the original Gournia town plan, 21" X 17.5 " needed to be Xeroxed in several small sections, and then joined together in a separate process. This resulted in a number of errors including distortion of scale and orientation between the several sections of the plan. At the same time, further problems were noted with respect to the original Hawes plan itself. For instance, it was difficult to interpret different aspects of the plan due to the nature of the original drawing conventions used. In addition, multiple errors were noted in the Hawes plan that had to do with an over-regularization and simplification of the houses, walls and roadways of the town.[1] This was especially important as the analysis of the town plan proceeded to study the orientations and areas of houses, roadways and walls. It was clear that there was the necessity for new and more accurate data and a new field survey was planned to undertake this work.

3 Electronic Total Station Survey 1995, 1997

During the summers of 1995 and 1997 a team from the Mediterranean Section of the University of Pennsylvania Museum of Archaeology and Anthropology undertook an electronic total station architectural survey of above ground features of the excavated Minoan town of Gournia. The work was carried out under a permit from the Greek Archaeological Service to Professor Vance Watrous, American School of Classical Studies at Athens.[2] The survey was keyed to the Greek Army Mapping Service 1:5000 topographical maps and geodetic benchmarks. The survey focused on diagnostic elements of the visible roadways, houses and walls of the excavated town and included aspects of the town, palace and the so-called 'ship shed' to the north of the town on the coast. In addition, portions of the Greek Army Mapping Service 1:5000 topographical map of the area were digitized.

Fig. 3. *Results of electronic total station survey of town.*

Fig. 4*. Geo-rectified balloon image of Gournia (merged from four quadrants).*

This survey did provide a more accurate plan of certain elements of the site although limitations of time prevented a survey of the entire town plan. For the elements of the town that were surveyed see **Fig. 3**. An attempt to produce a site-wide plan of Gournia was undertaken through a combination of the electronic total station survey work already accomplished together with the use of a low-level balloon photograph of the town by J.W. Myers.[3] Despite spatial distortions of the image, resulting from the irregular topography of the town, and the offset perspective of the photograph, it was possible to geo-rectify the balloon image. The result provided in many ways a more accurate representation of the lay-out of the town than the plan produced by Hawes in 1908.

4 Geo-rectification process

[1] This was later noted by J. Soles, "The Gournia Palace," *AJA* 95 (1991) p. 17.

[2] We thank Professor Watrous for his interest in this project and for his assistance. The members of the field team in 1995 included D. Andrianou, O. Tolba, K. Romano and D. G. Romano, Director. In 1997 the field team included K. Kourelis, N. Stapp, O. Tolba and D. G. Romano, Director.

[3] The authors thank Professor Myers for permission to use the balloon photograph in this study.

The low level balloon photograph was geo-rectified using the Rubbersheeting function in the CAD Overlay package of AutoCAD 2000. Other software, such as ERDAS Imagine and Idrisi can also be used for this procedure, however we found that CAD Overlay was the equal of, or superior to, these options. There is some error inherent in the process of geo-rectification, since the point of origin in the image can rarely be moved to the exact destination point determined by the survey. For our purposes we wished to keep this error as minimal as possible, usually within centimeters. **Table 1** is a representative example of the lower limits of error that we encountered, where the error is expressed in millimeters and at most a few centimeters.

In order to facilitate the process of geo-rectification, the balloon image was divided into four overlapping quadrants (**Fig. 4**). This was necessary due to the complexity of the image as well as our desire for a high level of accuracy in the rectified plan. The principle concern with this approach was whether or not the individual quadrants would align after being rectified separately. After completing this process there were some discrepancies between the four sections of the image. In most cases this error was only a few centimeters, the one notable exception being the border between the northeastern and southeastern quadrants. Here, in one case, the error approached 20 cm. This was likely due to the fact that there was not a great deal of survey data in this area of the town. Attempts at correcting this were not successful and, as a result, this portion of the 'plan' could not be relied upon for conducting later studies. Once rectified we generated a digitized plan of the town plan based upon the geo-rectified balloon photo (partial digitized plan, Fig. 5).

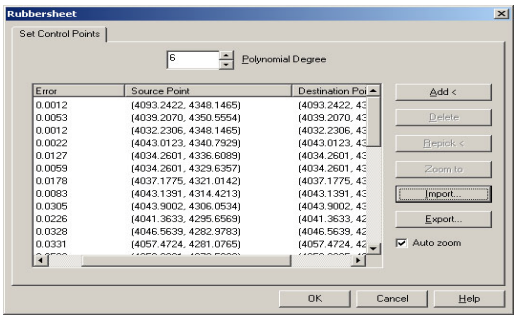

Table 1. *Error resulting from geo-rectification.*

While the digitized information cannot be held to the same standards of accuracy as the survey data, a test comparing the orientations of several of the major roads of the town, that had been both surveyed and digitized from the balloon photo, were compared. The results (Table 2) show that the discrepancies between the two are not significant.

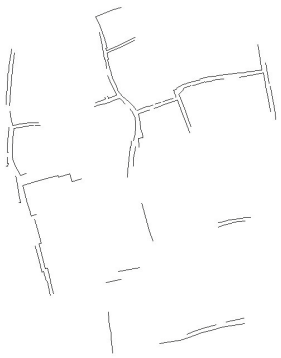

Fig. 5. *Digitized town roadways based on the geo-rectified balloon photograph.*

	Orientation of Roads from Digitized Plan	Orientation of Roads from Survey Data	Discrepancies in Orientations between Digitized and Surveyed Data
Valley Road	S 9d55'44" E	S 10d18'12" E	0d22'37"
Road East of House Cb	S 22d8'28" E	S 21d6'17" E	1d2'11"
Eastern Facade of West Court	S 14d10'15" E	S 15d15'12" E	1d4'57"
East Ascent D	S 74d37'40" W	S 73d5'42" W	1d31'58"
East Ascent C	S 80d13'13" W	S 80d7'22" W	0d5'51"
East Ascent A	S 81d56'36" W	S 81d49'36" W	0d7'00"

Table 2. *Comparative Orientations of Roads from Survey Data and from Digitized Plan of Balloon Photographs.*

5 Town Plan Analysis

The analysis of the new plan of Gournia began with a study of the orientation of various surveyed and digitized aspects of the town. It was anticipated that similarities or patterns of orientation might be indicative of Minoan surveying or town planning design. There were also immediate questions concerning the expected accuracy of such ancient surveying and the palace provided the test case in this regard. The size of the palace together with its prominence in the town and the quality of its masonry construction, presupposes some form of rudimentary surveying techniques being used in its planning and layout. (see balloon photo, Fig. 4).[4] Furthermore, as much of the palace was included in the electronic total station survey (Fig. 3), we could be confident about our data.

An examination of the palace revealed a degree of consistency in the orientation of its internal and external walls (Tables 3, 4), although some error exists. Since it is fairly obvious that the palace was planned as a structure composed of rectilinear elements there is every likelihood that the building was intended to have predominantly right angles in its construction and design.

[4] See J.Soles, "The Gournia Palace," *AJA* 95, 1991, pp. 17-78.

5.1 Roadway and Palace analysis

A comparative study was made between the orientations of the digitized roadways of the town and the orientations of the internal and external walls of the palace. The results indicate that portions of several of the main roads and alleyways are oriented in the same general direction as the Palace. This was especially found to be true with respect to the East Ascents, portions of the East and West Ridge roads and several of the smaller alleyways. Allowing for the variation found in the palace this evidence suggests that these roads were laid out along a similar, if not identical, orientation to the palace structure. Several of the structures, especially in C block, also follow this orientation.

5.2 House analysis

Our study also considered several of the houses from Gournia as discreet entities. This approach follows fairly closely earlier considerations of Minoan domestic architecture in which the emphasis is not with the precise arrangement of the house but rather with the incorporation of discreet architectural modules that could be arranged in various ways. Thus, the overall size and individual components of each house may be nearly identical even though the plans vary greatly from one example to the next. Two of the best preserved houses Ab and He were studied to determine the feasibility of this line of inquiry. For the purposes of this portion of the study, each room was digitized individually allowing for measurements of individual room area as well as wall lengths (perimeter).

Initially this work was carried out entirely using CAD Overlay, a module of AutoCAD, however, due to advanced database capabilities of ArcView that would prove extremely helpful for inter-house comparisons, we also attempted to digitize the houses using ArcView 3.2. Concerns were raised using ArcView for digitization and, as can be seen in Tables 5 and 6, there were differences, at times significant ones, in the comparison of the results of our digitizing work with AutoCAD and ArcView.

5.3 ArcView-AutoCAD comparison

These examples represent the most accurate and least accurate results of digitization. While some of the inconsistencies can surely be attributed to human error, the amount of variation of the ArcView results, in comparison with AutoCAD can also be attributable to the digitizing tools in ArcView. While ArcView does demonstrate a clear advantage in terms of analysis of the data as well as its presentation, the accuracy of the primary digitized data is not equal to the standard of AutoCAD. This problem could be circumvented by importing the digitized data from CAD Overlay into ArcView, using the CAD Reader extension. However, importing data in this way can cause difficulties in regards to database integration in ArcView, namely ArcView's database applications do not always recognize such information for functions such as area calculations without first altering the format of the AutoCAD data. Nevertheless it was decided that this was the best approach in view of the questions raised concerning the accuracy of ArcView's digitizing tools.

Fig. 6. *Balloon photograph of Palace at Gournia.*

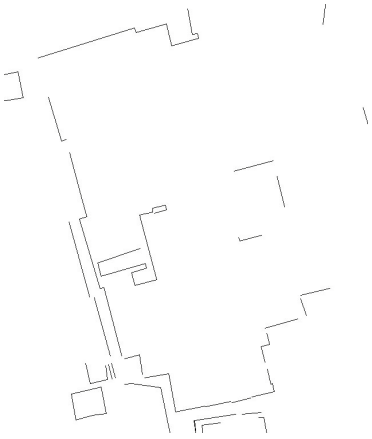

Fig. 7. *Electronic total station survey of Gournia palace.*

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6 Gournia Region

Beyond the immediate area of the Minoan town, we were also interested in the general region surrounding Gournia mainly due to the presence of known Bronze Age remain outside the town, most notably the so-called 'shipshed.'

	Orientation of east-west walls of palace	Orientation of north-south walls of palace
	N 74d42'40" E	N 14d31'11" W
	N 75d26'27" E	N 14d4'27" W
	N 75d0'19" E	N 16d13'20" W
	N 71d43'11" E	N 16d6'40" W
	N 74d22'50" E	
	N 71d37'30" E	
	N 75d15'47" E	N 14d4'27" W

Min.	N 71d37’30” E	
Max.	N 75d26’27” E	N 16d13’20” W
Ave.	N 74d01'14" E	N 15d29'35" W
SD	1d31'11"	0d21'45"

Table 3. *Comparative orientation of east-west and north-south walls of palace*

6.1 Greek Army 1:5000 Topographical Map

The Greek Army Mapping Service 1:5000 topographical map of the region was obtained and geo-rectified to correct for minor error. This was accomplished using the same methods as for the balloon photograph (above) although in this case corrections were made to the map by correlating the 500 m. grid system inherent in the map with a true 500 m. grid which we created in AutoCAD.

	Orientation of E-W portions of façade	Orientation of N-S portions of façade
	N 73d32'36" E	N 9d34'35" W
	N 74d25'1" E	N 13d36'15" W
	N 72d48'53" E	N 16d54'55" W
	N 76d1'20" E	N 15d15'12" W
	N 80d54'40" E	N 16d28'5" W
	N 78d59'59" E	N 14d47'34" W
	N 79d20'12" E	N 8d26'35" W
	N 75d45'57" E	N 10d15'39" W
	N 76d56'31" E	N 12d45'50" W
	N 75d9'53" E	N 15d4'27" W
	N 77d28'46" E	N 13d54'40" W
		N 15d35'44" W
		N 18d32'32" W
Min.	N 72d48’53” E	N 8d26’35” W
Max.	N 80d54’40” E	N 18d32’32” W
Ave.	N 76d28'57" E	N 13d56'18" W
SD	2d15'42"	2d52'18"

Table 4. *Comparative orientations of external palace walls*

6.2 Landscape Studies

The rectified map was used to create a DEM of the area by digitizing contour lines at intervals of 20 m. Although crude, this provided us with general topographical information concerning the environs of Gournia. The digitized map was further utilized to assist in the rectification of a 1 m. resolution IKONOS satellite image of the area.[5] The survey of the town and particularly certain landscape features to the north of town, including numerous terrace-like features and the so called ‘shipshed’ were helpful in the geo-rectification process.

The 1m. resolution satellite image was of little use to us in the study of the Minoan town, however we were able to conduct some remote sensing in the landscape surrounding Gournia based upon the image. This work was undertaken using the Supervised and Unsupervised Classification tools in Erdas Imagine 8.4.

[5] We are grateful to Dr. Barbara Hayden for the use of this satellite image.

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House Ab

	Areas, AutoCAD (m^2)	Areas, ArcView (m^2)	Area Differences (m^2)	Area Differences (%)
Room 1	3.3558	3.4806	0.1248	3.5855
Room 2	7.573	7.8981	0.3251	4.1161
Room 3	5.5009	5.526	0.0251	0.4542
Room 4	1.0971	1.1826	0.0855	7.2298
Room 5	9.0488	9.3154	0.2666	2.8619
Room 6	19.1761	19.5113	0.3352	1.7179
Room 7	5.4571	5.2567	0.2004	3.6722

House He

	Areas, AutoCAD(m^2)	Areas, ArcView (m^2)	Area Differences (m^2)	Area Differences (%)
Room 1	33.6156	33.4253	.1903	.5661
Room 2	14.5166	13.6488	.8768	5.9780
Room 3	14.3811	13.62	.7611	5.2923
Room 4	13.6509	11.9616	1.6893	12.3750
Room 5	3.2751	3.1258	.1493	4.5586
Room 6	6.0714	5.3762	.6952	11.4504
Room 7	3.4528	2.9872	.4656	13.4847
Room 8	6.5719	5.7480	5.7480	12.5367

Table 5. *Differences in Room areas digitized in AutoCad and ArcView.*

House Ab

	Perimeters, AutoCAD (m)	Perimeters, ArcView (m)	Perimeter Differences (m)	Perimeter Differences (%)
Room 1	8.2074	8.4003	0.1929	2.2963
Room 2	11.0587	11.2764	0.2177	1.9306
Room 3	9.6368	9.648	0.0112	0.1161
Room 4	4.9713	5.1667	0.1954	3.7819
Room 5	20.1024	18.5881	1.5143	7.5329
Room 6	34.4502	34.6762	0.2260	0.6517
Room 7	10.0566	10.0586	0.0020	0.0199

House He

	Perimeters, AutoCAD (m)	Perimeters, ArcView (m)	Perimeter Differences (m)	Perimeter Differences (%)
Room 1	22.2632	22.4253	0.1621	0.7728
Room 2	16.0389	15.6624	0.4215	2.3474
Room 3	22.8205	22.2656	0.5549	2.4316
Room 4	14.7090	13.8618	0.8472	5.7611
Room 5	7.4916	7.3336	0.1580	2.1090
Room 6	9.8436	9.2835	0.5601	5.6900
Room 7	7.7613	7.3367	0.4246	5.4707
Room 8	10.2684	9.6267	0.6417	6.2493

Table.6 *Differences in Room perimeters digitized in AutoCad and ArcView.*